PHILIPPINE JOURNAL OF OTOLARYNGOLOGY-HEAD AND NECK SURGERY VOL. 40 NO. 1 JANUARY – JUNE 2025

Low-Cost Phantom Model for Simulation Training in Ultrasound-Guided Ethanol Ablation of a Cystic Thyroid Nodule

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ABSTRACT

Objective: To describe a low-cost, reproducible phantom model for training medical practitioners in ultrasound-guided ethanol ablation (EA) of a cystic thyroid nodule.

Methods: The model of cyst contents was created using a mixture of coffee powder, cornstarch and water to mimic colloidal contents. This was injected into the finger of a cut surgical glove secured with transparent tape to serve as an inflatable capsule and placed inside a chicken breast. This setup allows practitioners to perform key ultrasound-guided ethanol ablation techniques including spinal needle insertion, cyst aspiration, saline flushing, re-aspiration and ethanol injection.

Results: The phantom model was assembled for PhP 150.30 per unit and took approximately 5 minutes to construct. This model was demonstrated to be a cost-effective and simple method for enabling specialists to practice and enhance their skills in ultrasound-guided ethanol ablation of a cystic thyroid nodule.

Conclusion: The described phantom model provides an accessible and practical training tool for healthcare providers to gain proficiency in ultrasound-guided ethanol ablation of a cystic thyroid nodule in a safe and controlled setting prior to actual patient handling.

Keywords: *ultrasound-guided ethanol ablation; cystic thyroid nodule; phantom model; simulation training; low-cost; reproducible; medical education; otorhinolaryngology; radiology; surgical training; ultrasound simulation; cost-effective model; ultrasonography; chicken breast model*

Thyroid ultrasound is a critical tool in the evaluation and management of thyroid diseases, facilitating the early detection and characterization of nodules, which are present in up to 67% of the general population.[1] Cystic thyroid nodules, which account for approximately 15-25% of all solitary nodules, are often benign but can cause discomfort, cometic concerns, or compressive symptoms. [2,3] Among treatment options, ultrasound-guided ethanol ablation (EA) has emerged as a minimally invasive and effective alternative to surgery, achieving a high success rate, low recurrence, and a volume reduction of 85-95% in completely cystic nodules.[4-8] However, EA requires proficiency in ultrasound guidance and precise needle placement, emphasizing the need for proper training.

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The authors declared that this represents original material, that the manuscript has been read and approved by the authors, that the requirements or authorship have been met by each author, and that the authors believe that the manuscript represents honest work.

Disclosure: The authors signed disclosures that there are no financial or other (including personal) relationships, intellectual passion, political or religious beliefs, and institutional affiliations that might lead to a conflict of interest

Presented at: Philippine Society of Otolaryngology – Head and Neck Surgery Descriptive Research Contest, August 29, 2024, Natrapharm Patriot Bldg, 18 West Service Rd, Parañaque City.

Data availability and sharing statement: Datasets for the study are publicly available in the data repository listed: Figshare [https://figshare.com/] with DOI: 10.6084/m9.figshare.28691999.v1

Philipp J Otolaryngol Head Neck Surg 2025; 40 (1): 37-41

Traditional training methods such as practicing on live patients or using commercial phantoms present challenges. Ethical concerns and patient safety limit live patient training, while commercial phantoms can be expensive and inaccessible, particularly in resource-limited settings.[9] Simulation-based training has been shown to improve procedural competency across various medical disciplines including ultrasound-guided interventions.[10-13] While synthetic tissue-mimicking materials (TMMs) are used in some training models, their high cost limits widespread adoption.[14-19] Past studies have explored the use of chicken breast as a cost-effective alternative for various ultrasound training models, including regional anesthesia and fine-needle aspiration.[11,13]

This study presents a novel, low-cost phantom model designed to simulate ultrasound-guided EA of cystic thyroid nodules. Using readily available materials, this model aims to provide a realistic and accessible training tool. The primary objective is to document the creation and use of this phantom model to establish a viable training tool that can improve the proficiency and safety of ultrasound-guided EA in clinical practice. The setup allows both the main proceduralist and the assisting person to experience the procedure in a way that closely mirrors real-life conditions.

METHODS

This study was granted exemption from ethics review by the East Avenue Medical Center Institutional Review Board (EAMC IRB 2024-82).

Material Selection Process

In selecting the materials for the phantom model, we considered various factors including cost, availability and sonographic properties. Initial trials involved materials such as gelatin and agar. Synthetic tissue-mimicking materials (TMMs) were also considered, however, these options were either cost-prohibitive or did not provide the desired sonographic properties. Ultimately, we selected chicken breast due to their cost-effectiveness and ability to closely resemble the acoustic properties of human tissue.

Preparation of the Phantom Model

The materials included one piece of chicken breast fillet, pure cornstarch, instant coffee powder, cling wrap, latex examination gloves and any transparent tape. *Table 1* outlines the consumable materials and the price of each material used including the cost to fabricate one phantom model.

To prepare the cyst solution, a mixture of 300 ml water, 15 mg cornstarch, and 15 mg instant coffee powder was combined and heated over low heat for one minute until it thickened slightly. After allowing the mixture to cool, 5 ml of the solution was injected into a cut latex

Table 1. Materials used to create the phantom model of a cystic thyroid nodule for ethanol ablation. Materials were sourced via GrabMart, Quezon City, Philippines as of June 6, 2024 from Acep Medical Supplies *https://www.facebook.com/acepmedicalsuppliestrading* via *https://mart.grab.com/ph/en/merchant/2-C33JEJVCR232VJ)* and The Marketplace *(https://themarketplace.com.ph* via *https://mart.grab.com/ph/en/merchant/2-C2VVUACDT2AEBE). Supplier details are listed in the footnote.*

Materials	Cost	Amount Needed	Computation	Computed Cost
Chicken Breast Fillet	PhP 162.00/ 500g	1 piece (approx. 150g)	162/500*150	P 48.60
Pure Corn Starch	PhP 24.00/ 200g	15 mg	24/200*15	P 1.80
Instant Coffee Powder	PhP 314.00/ 100g	15 mg	314/100*15	P 47.10
Cling Wrap	PhP 88.00/ 30 cm x 2000 cm	30 cm x 50 cm	88/(2000/50)	P 2.20
Latex Gloves	PhP 300.00/	1/5 glove	(300/100)/5	P 0.60
	box (100 pcs)			
Delivery Fee	PhP 50.00	1	50*1	P 50.00
TOTAL	PhP 150.30/ phantom			

All materials were sourced via GrabMart, an online grocery and medical supply delivery service available through the Grab App. Prices are based on listings from vendors available on GrabMart as of June 6, 2024. Prices may vary due to supplier availability, demand, and promotions. For real-time pricing and availability, visit www.grab.com/ph/mart or check the Grab app.

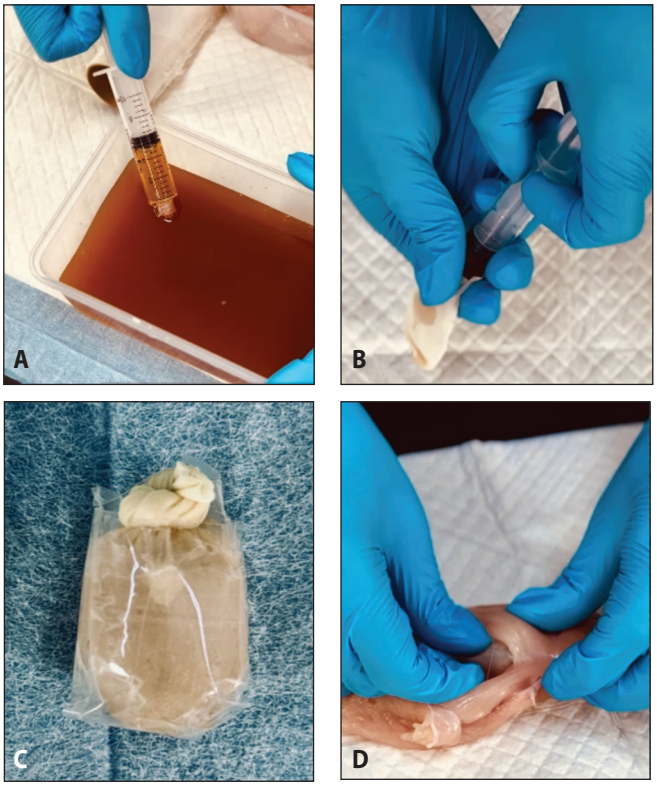

Figure 1. Illustration of the process of creating the phantom cyst model, including; the **A.** preparation of the cyst solution; **B.** injection to a cut latex glove finger; **C.** sealing using transparent tape; and **D.** embedding it within the chicken breast fillet

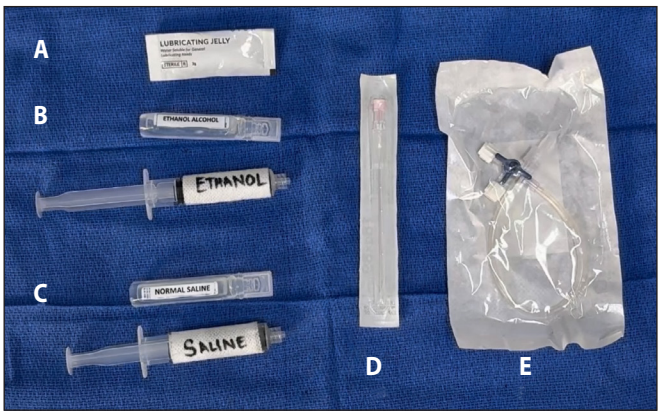

Figure 2. Materials needed for ethanol ablation simulation including **A.** lubricating jelly; **B.** ethanol; **C.** normal saline solution; **D.** G18 spinal needle; and (E) three-way stopcock

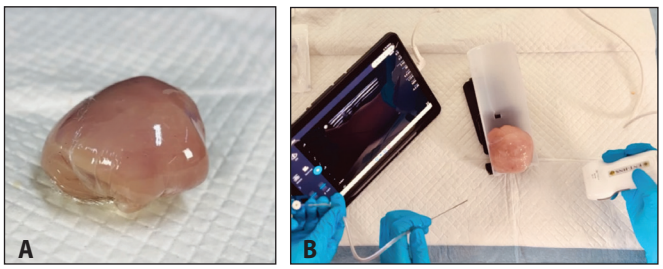

Figure 3. Depiction of **A.** the completed phantom model designed for ethanol ablation procedures; and **B.** setup for the simulation procedure

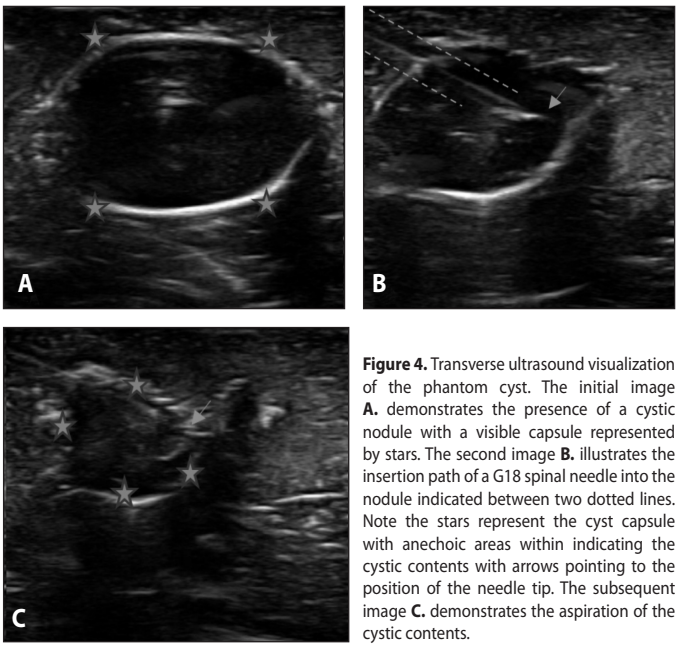

Figure 4. Transverse ultrasound visualization of the phantom cyst. The initial image **A.** demonstrates the presence of a cystic nodule with a visible capsule represented by stars. The second image **B.** illustrates the insertion path of a G18 spinal needle into the nodule indicated between two dotted lines. Note the stars represent the cyst capsule with anechoic areas within indicating the cystic contents with arrows pointing to the position of the needle tip. The subsequent image **C.** demonstrates the aspiration of the cystic contents.

glove finger, which was then knotted at the end and sealed with scotch tape to prevent leakage of the contents upon injection and aspiration. This solution was selected based on preliminary trials to mimic the appearance, viscosity and echogenicity of cystic fluid.

The next step involved preparing the chicken breast fillet by making a small slit to create a pocket. The prepared cystic nodule consisting of

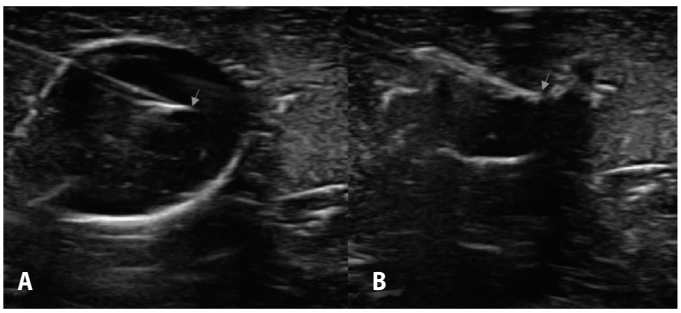

Figure 5. Ultrasound visualization of the phantom cyst during procedural steps showing the **A.** flushing and **B.** re-aspiration of normal saline solution. Note the arrow showing the needle tip position within the cyst capsule.

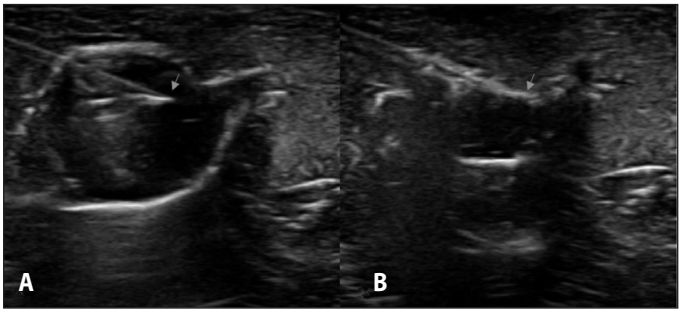

Figure 6. The second image illustrates the **A.** injection, retention; and **B.** subsequent re-aspiration of ethanol highlighting a reduction in cyst volume. Note the arrow showing the needle tip position within the cyst capsule.

the glove finger filled with the cyst solution was carefully inserted into this slit. The steps can be seen demonstrated in *Figure 1*. To maintain the structure and prevent displacement during handling, the chicken breast fillet containing the cystic nodule was wrapped with cling wrap. The preparation takes approximately 5 minutes, and the models can be prepared in batches and stored in a refrigerator for up to two weeks to maintain consistency. Appropriate personal protective equipment should be available and worn during the creation and handling of the model to ensure safety.

Procedure for Ethanol Ablation Simulation

For the simulation training, the constructed phantom model was placed on an ultrasound examination table. A portable hand-held ultrasound machine was sufficient and was used to locate and visualize the cystic nodule within the chicken breast fillet.[20] The procedure also utilized a three-way stopcock, gauge-18 spinal needle, plain normal saline solution and 95-99% ethanol. The normal saline solution and ethanol were both prepared beforehand, each in a 10-cc syringe, properly labeled to indicate the contents, with the spinal needle connected to a three-way stopcock. This simulated the preparatory set-up in an actual ethanol ablation procedure. *Figure 2* displays the materials needed for the ethanol ablation simulation training.

Figure 3 illustrates the completed phantom model and setup for the simulation procedure. After creating the phantom model, lubricating

gel was applied, and ultrasound images were obtained using a handheld Philips Lumify System 795005 with an L12-4 linear probe to demonstrate visualization of a model of a cystic lesion in the thyroid, and simulation of the ethanol ablation procedure of a cystic thyroid nodule was performed. The Philips Lumify System is manufactured by Philips Healthcare, headquartered in Andover, MA, USA.

Under ultrasound guidance, the guage-18 spinal needle was carefully inserted into the cystic nodule within the chicken breast. Cyst contents were aspirated using the spinal needle. After aspiration, the cystic nodule was flushed with plain saline solution, amounting to the volume of the cyst aspirated, to clear any residual colloidal material and then completed aspirated from the cyst. Ethanol injection was done using 95-99% ethanol measuring approximately 50% of the aspirated volume of the cyst contents, and was then retained within the cystic nodule for 2 minutes before being completely aspirated. Literature has shown that ethanol can be retained or re-aspirated after the procedure however complete removal may provide better comfort and less inconvenience with no risk of ethanol leakage.[4,8] With regards to the duration, studies comparing ethanol retention time and volume reduction has revealed that a retention time of 2 minutes was sufficient to achieve similar results to 5-minute and 10-minute retention times.[4, 6]

RESULTS

The ultrasound images obtained from the phantom model provided clear visualization of the cyst capsule and cyst contents. In the transverse view, as shown in *Figure 4,* the cyst capsule was well-defined with anechoic areas inside representing the cyst contents. This demonstrates the model's ability to replicate the acoustic properties of cystic thyroid nodules. This figure also shows the insertion of a G18 spinal needle into the nodule (with the arrows indicating the location of the needle) followed by the aspiration of the cyst contents.

Further procedural steps were captured in *Figures 5* and *6. Figure 5* illustrates the steps involving the flushing and re-aspiration of plain normal saline solution. *Figure 6* demonstrates the injection, retention and subsequent re-aspiration of ethanol. This final step effectively simulates the ethanol ablation process, demonstrating the appearance of ethanol as it is being infused into the cyst, highlighting the importance of maintaining visualization of the needle tip during the entire process, as ethanol leakage caused by a displaced needle tip can cause severe pain. Lastly, re-aspiration of the ethanol demonstrated the reduction in cyst volume which is the desired outcome in clinical practice. Replicability was assessed through multiple trials, focusing on the clarity of ultrasound images and the effectiveness to simulate the steps of ethanol ablation.

The results from the ultrasound images and procedural steps confirmed that the low-cost phantom model successfully simulates the key steps and ultrasound characteristics involved in ultrasound-guided ethanol ablation of a cystic thyroid nodule. The clear visualization of the cyst capsule and contents, accurate needle insertion, and effective simulation of aspiration and ethanol injection all indicate that the model is a valuable tool for training purposes.

DISCUSSION

The development of a low-cost phantom model for ultrasound-guided ethanol ablation (EA) of cystic thyroid nodules addresses a crucial gap in medical training. Ultrasound has become an essential tool in the management of thyroid diseases due to its non-invasiveness, real-time imaging capability, and affordability. However, effective use of ultrasound in procedures like EA requires proficiency in ultrasound guidance and needle placement, which necessitates extensive training.[11]

Despite its advantages, inadequate training in ultrasound techniques can lead to adverse outcomes. Lack of experience can make needle tip localization challenging and result in unintended needle placement.[21,22] For instance, a study on residents trained in ultrasound-guided central venous cannulation found that 64% of participants inadvertently penetrated the posterior wall of the target vessel in a human torso mannequin model.[23] Similarly, complications may also arise during EA of a cystic thyroid nodule, including perinodal ethanol leakage and intracystic hemorrhage due to increased vulnerability of the cystic wall to needle puncture after ethanol instillation.[24] This highlights the need for robust training methods to ensure accurate needle placement and avoid complications.

The results of this study demonstrate that the low-cost phantom model simulates with relatively high fidelity the experiential aspects of ethanol ablation of a cystic thyroid nodule. The model provided clear visualization of the cyst capsule and its contents, and accurately simulated needle insertion, aspiration and ethanol infusion. The reduction in cyst volume observed in the phantom model following ethanol ablation mirrored the desired clinical outcome post-procedure. Ethanol ablation, a minimally invasive, highly effective treatment for cystic thyroid nodules, with reported high success rates, significant nodule volume reduction, and minimal complications[3,4,5,6,7,8] makes it a preferable alternative to surgery in appropriate candidates. However, achieving proficiency in EA requires extensive training, underscoring the value of accessible training models like the one developed in this study.

Our model, however, is not without limitations. Clinicians have not independently verified this model, and therefore, further validation and attempts at model improvement are warranted.[25] To evaluate the

effectiveness of our phantom model, we plan to conduct validation studies involving feedback from practitioners who use the model. These studies will assess not only the anatomical accuracy of the model but also its effectiveness in simulating the procedural steps and outcomes of ethanol ablation. We aim to gather quantitative data on the proficiency and confidence levels of practitioners before and after training with the model, as well as qualitative feedback on the model's usability and realism. While this model closely approximates human anatomy, there are differences in sonoanatomy (i.e., enhanced echogenicity of the cyst capsule and simulated cyst contents) that should be understood prior to attempting to perform interventional techniques on patients. The biological materials used in the model such as chicken breast, are subject to decomposition, necessitating refrigeration to prolong the model's useful life to approximately two weeks.[11]

In conclusion, the low-cost phantom model developed in this study provides a practical, effective and accessible tool for simulation training in ultrasound-guided ethanol ablation of a cystic thyroid nodule. By enhancing the proficiency and confidence of practitioners, such models can contribute to improved patient outcomes and safer clinical practices. Future research should focus on validating the model's effectiveness through comparative studies and exploring its potential applications in other ultrasound-guided procedures.

ACKNOWLEDGEMENTS

The authors acknowledge Dr. Ronald Sadian, Dr. Genaro Trinidad, and Dr. Roxanne Castillo for their valuable contributions in conceptualizing the phantom model and identifying the training gap in our institution. Their insights were instrumental in shaping the objectives and design of this study

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